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ME FACTORS AFFECTING THE REPLACEMENT OF THE COMMERCIAL FRESH-WATER MUSSELS [1]

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INTRODUCTION

Serious depletion of any group of animals taken regularly for ommercial use is to be expected, as the natural replacement of such nimals rarely keeps pace with man's needs. An adjustment may e effected to some extent by limiting the harvest or by increasing the eplacement. However, when the replacement, either natural or rtificial, is hampered by radical changes in the natural habitat, the iological problem becomes quite involved. These statements are articularly applicable to the fresh-water mussels which supply the earl-button industry with its raw material, amounting to 30,000 ns of shells annually, as the mussels being sedentary animals are asily taken. Since these animals move slowly and laboriously they an not change location rapidly when any particular portion of the ream becomes unfavorable to them. Besides, because of a peculiar, omplicated life cycle the species of fresh-water mussels are de-endent in their natural reproduction upon certain species of fish hich in turn are subject to various factors in an unstable environ-ent; and, whether propagated naturally or artificially, the juvenile ussels present a very vulnerable stage at the beginning of a 5-year eriod required to produce commercial mussels.

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EXTENT OF SURVEY

Realizing that stream changes of considerable magnitude were taking place in the upper Mississippi River, and probably in other rivers as well, many of the mussel-bearing streams of Minnesota, Iowa, Wisconsin, Illinois, Indiana, Kentucky, Tennessee, northern Alabama, Mississippi, Louisiana, Texas, Arkansas, and Missouri have been investigated to ascertain the present status of the mussel fauna. More specifically, the waters examined were: The Mississippi River between St. Paul, Minn., and Cairo, Ill.; the Ohio River between Cairo, Ill., and Evansville, Ind.; the Tennessee River from its mouth at Paducah, Ky., to a point some 40 miles above Chattanooga, Tenn.; portions of the Cumberland River in Kentucky and Tennessee; portions of the Green River in Kentucky; portions of the Wabash and White Rivers in Indiana; the lower part of the Illinois River in Illinois; the Rock River in Illinois; the Kankakee River in Indiana and Illinois; the Fox River in Illinois and Wisconsin; the St. Francis, White, and Black Rivers in Arkansas; the Ouachita River in Arkansas and Louisiana; and the Trinity, Neuces, Brazos Rivers, and the Rio Colorado and Rio Grande in Texas. In addition to these major streams various small streams in Illinois, Indiana, Iowa, Missouri, southern Wisconsin, and southern Minnesota have also been studied.

The field observations and collections were made by parties traveling in an automobile, carrying special equipment, at various times during the past three years. In the Mississippi system during the past two summers (1930 and 1931) the survey was conducted from the Bureau of Fisheries floating laboratory (U. S. quarterboat No. 348). All field parties were equipped to make chemical and physical examinations of the streams as well as biological studies of the mussel fauna and other aquatic life. The material obtained was forwarded to the United States Bureau of Fisheries field station at Columbia, Mo., for final study.

In all of this work the natural replacement of fresh-water mussels, the condition of gravid females considered as potential breeding stock, and stream conditions were given particular attention. The findings are summarized in the following sections.

NATURAL REPLACEMENT OF MUSSELS

In studying the natural replacement of the various species of mussels the relative abundance of young and adults of each age was determined. Two criteria of age were used: (1) The actual size of the shells and (2) the annual growth rings. Chamberlain (1931) has applied the growth-ring method to the study of the age and growth of fresh-water mussels and finds that the approximate age of most individual mussels can be obtained by this method with comparative ease. The size and growth ring data obtained from the study of the shells collected in the present survey show that, in the streams examined, the natural replacement of commercial mussels during the past six years has been very slight throughout the Mississippi system except in certain small more or less isolated areas.

In various localities, however, particularly north of Grafton, Ill., the slough sand shell—a mud-loving species of little or no commercial

lue—seemed to be maintaining itself successfully, judging from e numbers of both young and adults found. Large numbers of venile and young fawns foot, paper shells, floaters, and fragile heel litters, all species capable of maintaining themselves on mud bot- ms and in shallow waters under various conditions unfavorable to llow sand shell, niggerheads, muckets, and pig toes, were taken in ckwaters and portions of streams slowed down by dams, or other structions throughout the Mississippi, Ohio, and Tennessee drain- es as covered in these surveys. No juvenile or young (less than 6 ars old) yellow sand shells, muckets, or niggerheads were taken Mississippi, Ohio, or Tennessee Rivers during the past two mmers (1930 and 1931).

At certain stations on the Trinity River and the Rio Colorado Texas and in various canals tributary to the Rio Grande near ercedes, Tex., juvenile and young southern yellow sand shells were ken in numbers large enough to suggest fair local replacement of at species.

A review of the summarized data from the upper Mississippi River La Grange, Mo., to Point Au Sable, Minn.) will suffice to make this ear. These data reveal that the average age of all individuals ken during the summer of 1930, representing the 15 most desirable mmercial species of mussels, ranges from five years in the cases the maple leaf, the hickory nut, the pocketbook, and the warty- ck through six and seven years for the pig toe, the butterfly, the ckhorn, and the yellow sand shell to 11 years for the niggerhead. must be pointed out that these values represent the average age all individuals taken, large and small, in collections where partic- lar effort was made to secure young and juvenile mussels, and that ese are not sorted collections such as a crowfoot bar would give.

In these same collections, which include approximately 5,000 shells, yellow sand shells, niggerheads, or washboards under four years age were found, and less than 10 per cent of the monkey faces, tterflies, fat muckets, pimple backs, buckhorns, and pig toes were ur years of age or less. The highest per cent of replacement found mong these 15 commercial species was that of the maple leaf, 37 er cent of the individuals of that species being four years of age younger. As may be demonstrated by the statistical analysis of ese data (to be presented elsewhere) the expectation for all of ese species of commercial mussels would call for approximately per cent (or more) of the individuals to be four years old or less natural replacement were merely maintaining the number of in- ividuals of these various species now present in these streams, and e only other commercial species approaching that value in replace- ent were the hickory nut with 33 per cent four years old or younger nd the maple leaf just mentioned with 37 per cent.

To these replacement values must be added some statement of the lative abundance of the species. In these upper Mississippi River llections the maple leaf, the pocketbook, the blue point, the pig e, and the buckhorn were all about equally common, and as a group cluded a large proportion of the commercial shells taken. Near ake Pepin considerable numbers of the fat mucket were collected. y comparison the yellow sand shell and the niggerhead were repre- nted by relatively few specimens, and these species had no replace-

ment under four years of age (actual under six years for the yellow sand shell and nine years for the niggerhead).

On the other hand large numbers of young paper shells, floaters and slough sand shells were taken, particularly back of wing dam and other obstructions to stream flow. In these same 1930 upper Mississippi collections the slough sand shell, pond paper shell, fragile paper shell and the stout floater were represented by approximately 2,000 specimens, having an average age of 3 or 4 years, and with the per cent of individuals 4 years old or less ranging from 55 per cent for the slough sand shell to 87 per cent for the stout floater.

Similar conditions as regards replacement were found in the portions of the Ohio and Tennessee Rivers covered in this survey, with of course the local differences in the actual species present.

These statements are based on studies of over 10,000 shells representing over 300 localities. As collections were made with self-closing dredges which covered 6 square feet of river bottom and brought up the entire sample—that is, the sand, mud, or gravel on the bottom with all of the contained mussels and other forms of life—and as these samples were then carefully examined by trained observers, these data are considered quite reliable. Thousands of individual dredgings were made. The dredge work was supplemented by hand collections (polliwogging, raking, and sieving). In fact, every effort was made to locate mussels of any and all sizes. Either the young of the various commercial species were present only in very small numbers, and there was therefore no considerable natural replacement in progress, or the young of these species were not located. This last alternative seems unlikely, as portions of the river from the shallow water along the shore to the deepest parts of the stream were sampled regardless of presence or absence of mussel beds, and the mussel beds themselves were worked to a depth of at least 2 feet below the floor of the river in many cases. Besides, the young of the other species of mussels were obtained in these same dredgings as were also both young and adults of many small non-commercial species as the peanut, deers-foot, and fawns-foot shell so that size was not a factor. Again in certain Texas streams both juvenile and young yellow sand shells were taken along with adults.

BREEDING STOCK AND GRAVID FEMALES

For the past four years extensive searches have been made for localities capable of supplying good breeding stock for the propagation of commercial fresh-water mussels. As the Lake Pepin mucket and the yellow sand shell are the two species which have been propagated by the United States Bureau of Fisheries in connection with the fish-rescue work, these two species have been given particular attention. In addition, however, gravid mussels of the river mucket, the pocketbook, and slough sand shells have been studied as well. Occasional gravid mussels of other species have been examined as opportunity offered. In this work samples have been taken from many localities and at various times throughout the year, as a result of the combined work of the fisheries staff and the cooperation of the button manufacturers.

In the upper Mississippi drainage a large per cent of gravid female ussels examined were heavily infested with both bacteria and usoria, and most of the glochidia were either destroyed leaving ly the empty shells in the marsupia or were reduced to an enfeebled dition before the optimum maturity required for either natural artificial propagation was obtained. The poor condition of the chidia was not only evident in the polluted streams below cities d factories, where the municipal and industrial wastes were poured o the streams, but even in small streams polluted by local wastes h as those from small cheese factories in Wisconsin. These condi- ns were found only in streams where pollution was evident.

This sterilization of gravid female mussels by substances and ganisms introduced into the stream with various municipal and dustrial wastes was found to be widespread and of course is an portant factor in the reduction of natural replacement of mussel ecies.

Three localities have been found, however, in the last year which er small quantities of fair to good breeding stock for the yellow d shells; namely, the northeast Arkansas district, (White, Black, d St. Francis Rivers), a portion of the Rio Colorado in Texas, and tain canals tributary to the Rio Grande in Mercedes, Texas trict.

RIVER CONDITIONS

EROSION SILT

The most outstanding factor producing changes in river conditions present throughout the Mississippi system was found to be erosion t. As a result of deforestation, current methods of tilling the land, d various improvements incident to commercial progress as road ilding, the amount of erosion silt which is being received by the rious streams of the Mississippi system has been progressively eater during the past 10 years until it now presents perhaps the st acute fisheries problem in our inland rivers. The general as- cts of this erosion problem from the standpoint of agriculture have en presented recently by Bates and Zeasman (1930), and general tements of the relation of erosion silt to mussel survival in the per Mississippi River have been set forth by Ellis (1931). The sion silt now carried by the streams of the Mississippi system is great that any obstruction to stream flow results in the rapid position of quantities of silt, on the upstream side of this obstruc- n. This is particularly true at times of high water, but most of e tributaries of the Mississippi system even in low water are now ickly clouded by the large quantities of erosion silt which are ured into them from the surface run-off following even local rms. This condition did not obtain years ago when swamps, rested areas, and other natural features impeded the surface run- . During the past summer (1931) the Tennessee River above ducah, Ky., was observed to change from a relatively clear stream one turbid with silt in suspension in the course of a few hours llowing a local thunderstorm in the Duck River region.

Field work on the Mississippi, Ohio, and Tennessee Rivers during e past summer (1931) revealed these deposits of silt behind all

sorts of obstructions, large or small, wherever the stream flow was slowed down, and actual measurements of these silt deposits ranged from few inches to 27 feet in depth, with a deposit greater than 1 inches the rule.

Erosion silt affects the mussel population of the river at once in several ways. Being sedentary animals of very slow locomotion fresh-water mussels are unable to move with any speed from the par ticular portion of the stream occupied by them even if other suitabl habitats are available; and as the entire bottom of the river does no present a favorable environment for mussels even in unpollute streams, the mussels are therefore more or less concentrated in th available suitable habitats. The deposition of erosion silt behind an obstruction to stream flow, be it temporary or permanent, covers al mussel beds above this obstruction for a distance depending upon th size of obstruction. This takes place so rapidly that the mussel are unable to find suitable new locations, because of their slow loco motion, and must remain in the silted area where, if the silt become deep enough, they perish.

Formerly when the silt load of the river was not large most of th mussels survived the deposits of silt during the high water. Thes deposits were not so overwhelming as those being laid down in th streams at present and were partly swept away during the inter vening periods of relatively clear water. However, there are variou places in the Mississippi system where one may see beds of dea mussels which were buried under mud and silt at some time in th past, due either to the stream changing its course or to some facto causing a sudden increase in the silt load.

Under the conditions which have developed following the change in the surface of the land incident to civilization, and which hav become particularly acute in the past 10 years, the mussel beds ar now subject to frequent and sudden changes in the turbidity of th stream. The load of erosion silt has become so great that eve temporary obstructions may cause a deposit of silt sufficiently larg to smother out whole mussel beds in a relatively short time. I many places in the various rivers studied, this condition has bee observed and beds of valuable mussels have been wiped out in a fe weeks by the silt deposits behind temporary obstructions of log or other débris. Where wing dams or other permanent obstructio have been placed in the streams not only are mussels smothered ou above the obstruction by silt deposits in the slack water, but th changes in current produced by these obstructions often erode exis ing bars and mud banks and bring more sand and mud down upo the mussel beds below. Mussels require relative stability of botto conditions and do not maintain themselves in bars which are cuttin away, consequently the permanent obstructions are harmful both i producing the deposit of silt above them and in facilitating the cu ting away of other bars below.

The deposits of erosion silt also curtail the survival of youn mussels. When the juvenile mussels first arrive at the bottom o the stream after completing their transformation they are less tha one-tenth of an inch in diameter, and later but while they are sti less than one-half of an inch across these young mussels partly ancho themselves with mucous threads. It is obvious that these sma

animals, particularly those attached by mucous threads, would be overwhelmed by deposits of silt which might not be so serious to adults. In fact, various mussel beds were observed in which the adult mussels were temporarily surviving silt deposits because the spaces between the gravel and stones of these beds were large enough to give room for the settling of the silt without burying the adults. It is only a question of time if conditions now existing continue until these adult mussels will be covered also.

Silt also affects the mussel survival of both young and adults through the oxygen supply, as was demonstrated by field determinations of the oxygen saturation in various silt carrying streams. Even silt from tilled land and road ditches carry with it a certain amount of organic material and on settling to the bottom of streams creates an oxygen demand, so that in addition to mechanically burying the mussels covered by it the silt changes the oxygen balance. A small layer of silt may therefore appreciably reduce the amount of oxygen available in the waters immediately above the floor of the stream. Juvenile and young mussels are very sensitive to oxygen reduction, and adult mussels usually become inactive when the oxygen tension of the water is reduced to 20 per cent saturation or less. (Unpublished data supplied by H. Chipman.)

If the volume of erosion silt continues to increase in those mussel-bearing streams as the present indications suggest, conditions similar to those in the Missouri River, the Arkansas River, and the Mississippi River below the mouth of the Missouri may be expected. The Missouri and Arkansas Rivers have never been mussel-producing streams because of their well-known loads of erosion silt which they bring in from the treeless plains through which they pass.

MUNICIPAL AND INDUSTRIAL WASTES

The influence of erosion silt on oxygen becomes even more serious when municipal and industrial wastes are added to the erosion silt. Below cities the silt deposits were found to carry down with them various kinds of organic débris which have been added to the stream by municipal sewage. These organic materials, varying from tiny particles to whole carcasses of animals, are coated with silt and imbedded in it. Consequently they decompose very slowly, create a large oxygen demand, and give off in some localities large volumes of noxious gases. Fresh-water mussels in such habitats are rapidly killed out, and the toxic substances from this mixture of decomposing organic wastes are projected downstream onto other mussel beds below.

The local effects of industrial pollution on mussel beds are well known and the action of strawboard wastes will serve as an example. Wherever concentrated industrial wastes are poured into the streams the fresh-water mussels suffer because of their inability to change location quickly and because of the ease with which the blood of fresh-water mussels takes up the various substances in the surrounding waters (Ellis, Merrick, and Ellis, 1931). One of the striking finds of the survey work here reported was evidence that industrial stream pollution from the upper Ohio River extends at times as far downstream as Paducah, Ky.

RIVER IMPROVEMENT

Another factor which must be considered in connection with the existing river conditions and their bearing on the mussel situation is the revival of river navigation. The perfection of the new tunnel-hull Diesel boats and the authorization by Congress of various programs of canalization for our major streams have given river navigation in the Mississippi system at this time a new commercial significance.

The construction of wing dams, hurdles, revetments, and permanent dams as part of this program of river improvement affects the mussel beds directly in producing changes in stream flow. As already pointed out in a previous section, the erosion silt load has increased so enormously in the past few years that any sort of obstruction of stream flow in most of the tributaries of the Mississippi system will produce a marked deposition of silt behind the obstruction. The covering of the mussel beds by this silt layer with its contained sewage and other wastes is equally detrimental to the mussel fauna whether produced by natural obstructions or by these river improvements for navigation. The wing dams and large dams do have the added factor, however, of permanence, whereas the natural obstructions are more likely to be temporary. The extermination of the mussel fauna back of these permanent obstructions is not at present the result of conditions peculiar to dams, but the result of the heavy load of erosion silt, municipal sewage, and industrial waste which these streams are now carrying and which are destroying mussels and other stream inhabitants in various localities where dams do not exist. It is true that the construction of these dams localizes the changes now going forward.

Extensive and rapid reduction, amounting in many places almost to extermination, of the mussel fauna is to be expected if the erosion and pollution problems are not solved, in view of the various improvements for navigation now existing or already authorized throughout the Mississippi, Ohio, and Tennessee systems.

What conditions back of wing dams and in the pools which these river improvements produce might be as regards the mussel fauna were the problems of erosion silt and pollution solved, can not be stated at this time. Coker 1930, page 216, reports that following the construction of the Keokuk Dam and other river improvements in the Keokuk (Iowa) region that the "yellow sand shell, formerly relatively scarce, had become a very common mussel by 1926" and adds that "the chief cause [of this increase in the yellow sand shells] may, however, be the development of a condition of stability in the areas between the wing dams," since he found "that away from the channel and between successive wing dams are broad areas of shallow water, which seem to be affording now (1926), in many places at least, just the right conditions for the growth and reproduction of yellow sand shells." Visiting this same region in the summers of 1930 and 1931 the writer found the areas mentioned by Coker to be largely silted over, often with a foul-smelling mud, presenting essentially a mud habitat, and that the yellow sand shells had disappeared almost entirely. The inference might be made that had these areas been protected against the erosion silt and pollution that the yellow

and shells might still be maintaining themselves there, but various ther factors may have operated against this species. Recognizing hat several factors may have contributed to the disappearance of he yellow sand shell behind these wing dams, it is certain that the reat increase in silt deposition which has taken place there in the ast five years has so changed the bottom conditions of these areas hat they are now no longer suitable habitats for the yellow sand hell.

OTHER FACTORS

The changes now going forward in our inland rivers due to ero- ion and pollution are operating in several ways against the fish auna of these streams, and therefore indirectly but nevertheless itally against the mussel fauna in another way. The changes in ish fauna have resulted in a marked reduction of many of the host ishes which carry the parasitic stages of the fresh-water mussels. This produces a curtailment of the natural reproduction of these nussels. A conspicuous exception is the increase of the gar, the host of the yellow sand shell, which mussel, however, has declined rapidly n the polluted streams in spite of the increase of its host fish.

Due to low water, economic conditions, and changes in the laws protecting the fresh-water mussels, large numbers of people have found it more or less profitable to collect shells, particularly by olliwogging and raking, during the past two summers. This hand collecting has been very destructive to several species, particularly he yellow sand shell, as the gravid females of this species gradually move into near-by shallow water when ready to spawn as the host ish, the gar, works in close to shore when feeding. One sheller on he St. Francis River in Arkansas told the writer that during May nd June hundreds of female yellow sand shells were easily picked p at night in shallow water by the light of a hand searchlight. Other shellers confirmed this observation.

SUMMARY

(1) The natural replacement of commercial mussels has been very slight during the last six years throughout the portions of the Mississippi, Ohio, and Tennessee drainages studied.

(2) In various localities north of Grafton, Ill., the slough sand shell, a mud-loving species, of little or no commercial value, was found to be maintaining itself successfully.

(3) In the Trinity River, the Rio Colorado, and in canals tributary to the Rio Grande at Mercedes, Tex., juvenile and young yellow sand shells were found in numbers large enough to suggest a fair local replacement of that species.

(4) No replacement of yellow sand shells under 6 years of age or niggerheads under 9 years of age was found in the portions of the Mississippi, Ohio, and Tennessee drainages studied during the last two summers.

(5) In the upper Mississippi River only two, the maple leaf and hickory nut, of the 15 principal species of commercial mussels showed a replacement with young mussels 4 years old or younger approaching that required to maintain the species.

(6) Throughout the Mississippi, Ohio, and Tennessee drainages as followed in this survey large numbers of young paper shells and floaters were found particularly back of wing dams and other obstructions to stream flow.

(7) The marsupia of gravid females of the yellow sand shell, the slough sand shell, the Pepin mucket, the river mucket and the pocketbook were found to be heavily infested with bacteria and infusoria. Most of the contained glochidia either had been destroyed or were in an enfeebled state. This condition was found to be widespread, and it has been very difficult to obtain suitable breeding stock for propagation work.

(8) Three localities offering small quantities of fair to good breeding stock of the yellow sand shell have been located in northeastern Arkansas and in southern and central Texas.

(9) The most outstanding factor producing changes in river conditions throughout the Mississippi system—that is, the Mississippi, Ohio, and Tennessee drainages—is erosion silt.

(10) Erosion silt is destroying a large portion of the mussel population in various streams by directly smothering the animals in localities where a thick deposit of mud is formed; by smothering young mussels even where the adults can maintain themselves; and by blanketing the sewage and other organic material which in turn produces an oxygen want that lowers the oxygen content of the water to the detriment of those species requiring well-aerated water. Very young mussels are particularly sensitive to the low oxygen tension in the water.

(11) Extensive and rapid reduction, amounting in many places almost to extermination, of the mussel fauna is to be expected if the erosion and pollution problems are not solved, in view of various improvements for navigation now existing or already authorized throughout the Mississippi, Ohio, and Tennessee drainages.

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